

Considerations in Collaborative Robot System Designs and Safeguarding

Tina Hull and Monika A. Minarcin
Omron Automation and Safety

ABSTRACT

Applications using industrial robotics have typically led to establishing a safeguarded space encompassing a wide radius around the robot. Operator access to this hazard zone was restricted by a combination of means, such as hard guarding, safeguarding, awareness means, and personal protective equipment. The introduction of collaborative robots is redefining safeguarding requirements. Many collaborative robots have inherently safe designs that enable an operator and a robot to work within a shared, collaborative workspace.

New technology in industrial robotics has opened up opportunities for collaborative operation. Collaborative operation could include either industrial or collaborative robots, depending on its application. The current defined modes of collaborative operation are hand guiding; speed and separation monitoring; safety-rated monitored stop; and, power and force limiting.

Collaborative robots and collaborative operations change what safeguarding will be required and how the system will be designed. Industry needs will continue to push this technology to include higher speeds and more capability while finding new ways to make the interaction between the collaborative robot and operator smarter and safer.

CITATION: Hull, T. and Minarcin, M., "Considerations in Collaborative Robot System Designs and Safeguarding," *SAE Int. J. Mater. Manf.* 9(3):2016, doi:10.4271/2016-01-0340.

INTRODUCTION

The safety standards for industrial robots have been developed over many years and are based on best practices gleaned from user experience and lessons-learned following workplace accidents. Implementing requirements for safeguarding have kept accident rates low, primarily by keeping operators away from the hazards.

Collaborative operation allows operators to be close to the collaborative robot under conditions in which contact might otherwise occur. While industrial robot safety standards may not be practical for collaborative operations, safeguarding may be needed to protect the operator when limits are outside the acceptable range. The primary goal of any automation system is to achieve a high level of productivity while keeping the operator safe [1]. The challenge is to use existing knowledge as a basis for understanding and better defining new limits for an emerging technology that changes how humans interact with collaborative robot systems.

Responsibilities

The operator has primary responsibility for system safety, according to standards ANSI RIA R15.06-2012 [2] and ISO 11161 2007 [3]. The operator is defined as any person given the task of installing, using, adjusting, maintaining, cleaning, repairing, or transporting machinery [2,3].

Note: Many ANSI standards define the operator role using descriptors such as individual, operator, installer, personnel, integrator, and supplier [2,4].

Causes

Studies in Sweden and Japan indicate many robot accidents do not occur during normal operation, but rather when operators are performing installations, maintenance, and adjustments [5]. These accidents often are caused by unpredictable speed and motion events triggered by sensor motion unintentionally power activation, or programming-sequence error.

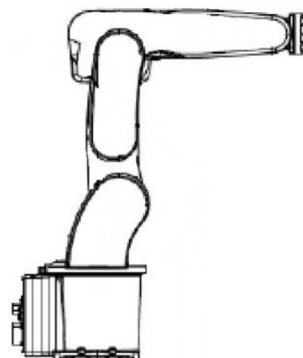


Figure 1. Singularity position for an industrial robot. (Image provided by Omron Corporation.)

A known hazard with industrial robots is singularity as shown in Figure 1, when the joint velocity (in joint space) can become infinite to maintain Cartesian velocity, thus producing high axis speeds [6]. This erratic function during programming use has led to many. Many potential injuries have been reported by new requirements in

the standards to either stop the robot and provide a warning before this occurs, limit the maximum speed and provide a warning, or to control it without creating a hazardous motion.

RISK ASSESSMENT

A risk assessment is required for all industrial and collaborative robot applications [6,7]. The integrator conducts the risk assessment, with the end-user participating. It should be a group task including operators and safety experts. During collaborative operations, special consideration should be made for tasks where contact between the collaborative robot and the operator is possible.

Hazard Zone

ISO 12100 2010 defines hazard zone as any space within or around machinery in which a person can be exposed to danger [8]. Sources of hazards include, but are not limited to, human errors, control errors, unauthorized access, mechanical failures, environmental sources, power systems, and improper installation and design.

The hazard zone for an industrial robot system includes the robot, end-effector, workpiece, and any device activated from the robot's control system [9]. Hazards arise from operational characteristics, including high-energy movement through a large operational space, movement and varying paths being difficult to predict, and overlapping operating space with other robots and machines. Because of these hazards, a restricted space is calculated and used to define a safeguarded space that restricts operators from entering the hazard zone.

Collaborative robots used in a collaborative operation are designed for operators to work in close proximity. The operating space is defined as the area where the operator may not enter while the collaborative robot is in motion [6]. The space within the operating space where the robot (including end-effector, workpiece, and fixture) and the operator can perform tasks concurrently is known as the collaborative workspace [6].

Hazard Identification and Safeguarding

With industrial robot applications, few human factors are considered since correctly designed and implemented protective devices stop hazardous motion before the operator reaches the robot [10]. Protective devices - such as safety-rated light curtains, area scanners, electro-mechanical switches, non-contact switches, mats, edges, bumpers, 3-D vision systems, sensors, and two-hand controls - monitor the operator's action and initiate stop commands when necessary. Hard guarding, such as fencing, is commonly used for areas where access is not needed and as a supplement for the safeguarding.

In collaborative robot applications, human factors are more likely to lead to contact since the operator is in close proximity to the collaborative robot, end-effector, work-piece, and fixture. The type, location, and force of the contact are important criteria when designing a system and keeping limits below acceptable threshold values. The difference between quasi-static and transient contact can

affect the duration of the exposure and the ability to retreat away from the hazard [6]. The threshold of pain varies for different regions on the body and can affect operator location and movement [11]. The operator's neck and head are considered critical areas and not allowed to have any contact with a collaborative robot [11].

System design should consider the operator's physical and mental limits, such as stress, fatigue, and ergonomics, common errors, reflexes, training, skill levels, and time limit constraints. In some cases, safeguarding with devices such as the safety-rated area scanner or 3-D vision system may be needed to detect deviations or additional personnel [12]. A SQL database could track production rate and indicate when productions falls below a limit, as a way to indicate human fatigue or potential issues with the system [13]. Tracking how often the reset and restart pushbutton is activated could indicate issue trends since this action is usually required for collaborative robot applications only when an abnormal condition has caused a stop.

Hazard Identification Unique for Collaborative Operation

The primary new hazard for collaborative operation is contact between the operator and the collaborative robot, its end-effector, fixture, and the workpiece [6]. Applications that involve tooling or work pieces with sharp edges or extruding pieces; systems that can create a spark and require shielding (such as arc flash from welding); anything with extreme temperatures capable of causing frostbite or severe burns; and, hazardous characteristics such as water-jet or laser cutting should be evaluated for inherent hazards and additional levels of guarding to reduce the risk of operator exposure.

The design should consider and account for impact on the operator if the collaborative robot loses its workpiece. The design also should address operator motion (approach and exit locations, extended reach, picking up dropped parts); speed and impact from clamping fixtures; personal protective equipment interference; operator's ability to retract upon contact; and, impact based upon robot, operator, and surrounding fixtures.

Task Identification

With industrial robot applications, safeguarding is designed to detect and prevent all hazardous motion if an operator entered the safeguarded space [6]. Even so, other drive-power hazards can still exist even if the robot is not moving. In some cases, different levels of drive power, such as teach or auto mode, could have different levels of hazard. While a collaborative robot is designed to be inherently safe [6], additional equipment within the system may not have the same performance level or safe design. A risk assessment should indicate if additional safeguarding is needed.

While a collaborative robot is inherently safe by design, the operator's tasks impact the overall design of the system. One thing to consider is how long the operator is in the collaborative space since time can affect the frequency and duration of contact between the operator and the collaborative robot. A minor injury sustained by a single, short contact could become more serious if it is repeated frequently or if the time is extended.



The transition into the collaborative space is a factor when it requires the collaborative robot to slow its speed or stop before the operator enters. It may also affect what end-effector and fixturing may actuate when the operator is present. System applications such as clamping, part release, and fluid dispensing may create hazards. When and how the collaborative robot may resume faster speed or perform tasks not permitted when the operator is not present should also be determined. The system may need different safeguarding if the tasks require multiple operators within the collaborative workspace or when additional procedures may affect the operator's location, reachability, or stamina.

In most collaborative applications, the robot has to know when the operator is within the safeguarded or collaborative space. This detection often is achieved with safety-rated presence sensing devices such as light curtains, safety mats, and area scanners.

Many designers prefer an area scanner for its ability to slow down motion in the space as the operator approaches. A gradual slowdown may increase the life of the robot by reducing wear and tear. An industrial robot application requires a category 0 stop when an operator enters the safeguarded space [2]. *Note that a category 1 stop is allowed when it is a time-delayed stop that will lead to a category 0 stop* [2]. A collaborative robot application may maintain its power in a category 2 stop, thus allowing for an automatic restart, which could increase cycle time [2].

A common use for collaborative robots is the ability to quickly reconfigure a system, making it a solution for applications with short lifecycles [5]. The area scanner zones are typically easier to reconfigure with software compared to hardware adjustments required for other presence-sensing devices.

Risk Reduction

Risk reduction in industrial robot systems is primarily achieved through safeguarding. With collaborative applications, risk reductions usually are achieved through the collaborative robot's inherently safe design features such as a seven degree of freedom manipulator, force sensing, compliant mode, low-inertia servo motors, elastic actuators, collision detection, safety-rated axis limits, and redundant encoders [6].

Industrial and collaborative robots have different risk reduction requirements. With an industrial robot, for example, the safety area scanner could be used to slow down the robot speed as the operator approaches the hazard, and then send a signal to stop the robot when the operator enters the safeguarded space. In a collaborative robot application, the same scanner could slow down the robot, but the slow down speed may be different since the robot may continue to move when the operator enters the collaborative space. The collaborative robot only stops if the operator enters the operational space. In many cases, the operational space would allow the collaborative robot to operate at speeds higher than the allowed limits based on the relationship between transferred energy and robot speed during transient contact or perform hazardous tasks when the operator is not present.

Without safety-rated presence sensing devices, an operator may not be aware of a system's activated power status. Indicator lamps or warning signals should be considered when unexpected motion could cause a hazard.

Stop

There are two types of stops, emergency stop and protective stop, and each one is active for different reasons [6,14]. The machine directive clearly states systems shall have an emergency stop. The only exception to requiring an emergency stop is when it does not provide additional safety [14].

For industrial robot system, common emergency stop requirements are that it has to be continuously operable, readily accessible, manually initiated, capable of overriding all other functions, and maintained once activated. In most application this is achieved with a red mushroom-shaped pushbutton with a yellow background. For systems with a longer span of control, it may also be achieved with an emergency stop pull-rope [15].

Having an emergency stop pushbutton on the collaborative robot may impede its functionality and not provide additional protection. Many collaborative robots are designed to perform the emergency stop function by a force pushing on the collaborative robot, and their controls are by an internal safety rated circuit. The risk assessment would indicate if additional emergency stop devices are needed based on unique applications or due to other machinery within the system.

Any detected failure in the safety-related parts of the control triggers a protective stop. With industrial robots the protective stop is initiated by safeguarding devices. Unlike emergency stops, which are initiated by the operator to immediately shut down the whole system, protective stops may shut down zones while allowing hazardous motion that could put the operator risk.

The protective stop may be initiated by safeguarding devices for a collaborative robot, or the collaborative robot may be equipped with a category 2 safety-rated monitored stop function [6].

SAFEGUARDING

Industrial Robot

Applications utilizing industrial robotics have typically led to establishing a safeguarded space that encompasses a wide radius around the industrial robot. This area includes machinery associated with the system's process, end-effector, work piece, fixtures, or machinery controlled by the industrial robot. The total area could be reduced when the design prevented operator access to the hazard at all times [2]. An example would be placing the robot close to a wall or adding hard guarding with spacing too small for an operator to access. Operator presence is not permitted within the hazardous zone. Access is limited by a combination of means, which may include hard guarding, safeguarding, awareness means, and personal